AF DUS&T

Raytheon

Dual Use
Micro Electro Mechanical Systems (MEMS)
Application Results in
Low Cost Technology Solution for Antennas

Todd Kastle, AFRL/SNRR, todd.kastle@wpafb.af.mil

AIR FORCE DUS&T PARTNERSHIPS

AF DUS&T

Raytheon

Air Force Research Laboratory (AFRL)and Raytheon have entered into a strategic dual use partnership to drive the cost of radar and communication systems down.

Todd Kastle, AFRL/SNRR, todd.kastle@wpafb.af.mil

PROBLEM

AF DUS&T

Raytheon

- Current gimbaled antennas lack the performance desired for multiple target track.
- Current Electronically Scanned Antennas (ESA) have the desired performance, but are expensive to purchase.

- Solution: AF DUS&T programs are developing Low Cost antennas that are 10% the cost of existing antennas

Todd Kastle, AFRL/SNRR, todd.kastle@wpafb.af.mil

OUTLINE

AF DUS&T

Raytheon

Millimeter Wave Electronically Scanned Array

MEMS Continuous Transverse Stub

MEMS Electronically Scanned Array

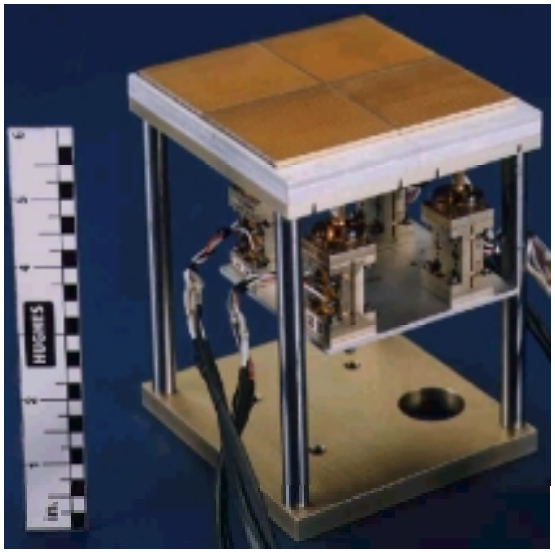
Summary

Todd Kastle, AFRL/SNRR, todd.kastle@wpafb.af.mil

Millimeter Wave Electronically Scanned Array

AF DUS&T

Raytheon



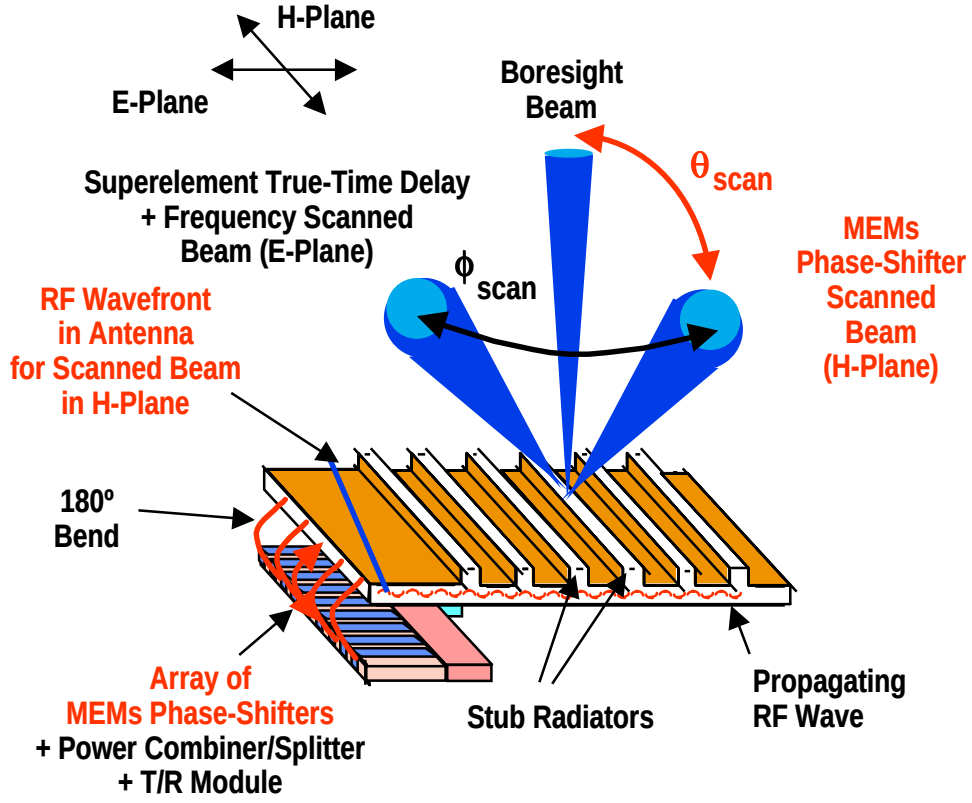
- Millimeter Wave Continuous Transverse Stub (CTS) Electronically Scanned Array for precision weapon delivery
  - –Laser like accuracy in weather and smoke
  - –High quality High speed SAR maps
  - –Apertures for both weapon and sensor
  - –Inherent ECCM capability
- Low cost technology
- Performance demonstrated!

Todd Kastle, AFRL/SNRR, todd.kastle@wpafb.af.mil

MEMs CTS ESA Concept Offers "Thinned" ESA Benefits

AF DUS&T

Raytheon



The MEMs CTS ESA concept achieves 2D scan with a number of Transmit/Receive(T/R) modules proportional to n, instead of n x n

i.e., fewer T/R modules

–> Lower-cost
–> Lower prime power
–> Lower weight

Todd Kastle, AFRL/SNRR, todd.kastle@wpafb.af.mil

MMW ESA Commercial Application
CTS CELLULAR RELAY ANTENNA

AF DUS&T

Raytheon

- Continuous Transverse Stub (CTS) antenna design uses high volume manufacturing technologies
  - –Injection molded plastics
  - –Extruded aluminum shapes
  - –Fabricated plastic sheet
- Antenna assembled in less than 15 minutes as compared to hours for existing antenna
- Over 5000 sold for Telecommunication Relay use

Todd Kastle, AFRL/SNRR, todd.kastle@wpafb.af.mil

OUTLINE

AF DUS&T

Raytheon

Millimeter Wave Electronically Scanned Array

MEMS Continuous Transverse Stub

MEMS Electronically Scanned Array

Summary

Todd Kastle, AFRL/SNRR, todd.kastle@wpafb.af.mil

MEMS CTS

AF DUS&T

Raytheon

Establish proof-of-concept for an X-band continuous transverse stub (CTS) antenna subarray that is scanned electronically in one dimension using a linear array of Micro Electro Mechanical System (MEMs) phase-shifters with MEMs metal-metal contact series switches.

This innovative electronically scanned antenna (ESA) subarray is the first step in the development of a low-cost, lightweight, 2D ESA for such major products as:

- **X-band military radar systems**
- **X-band commercial aircraft radar/communications**

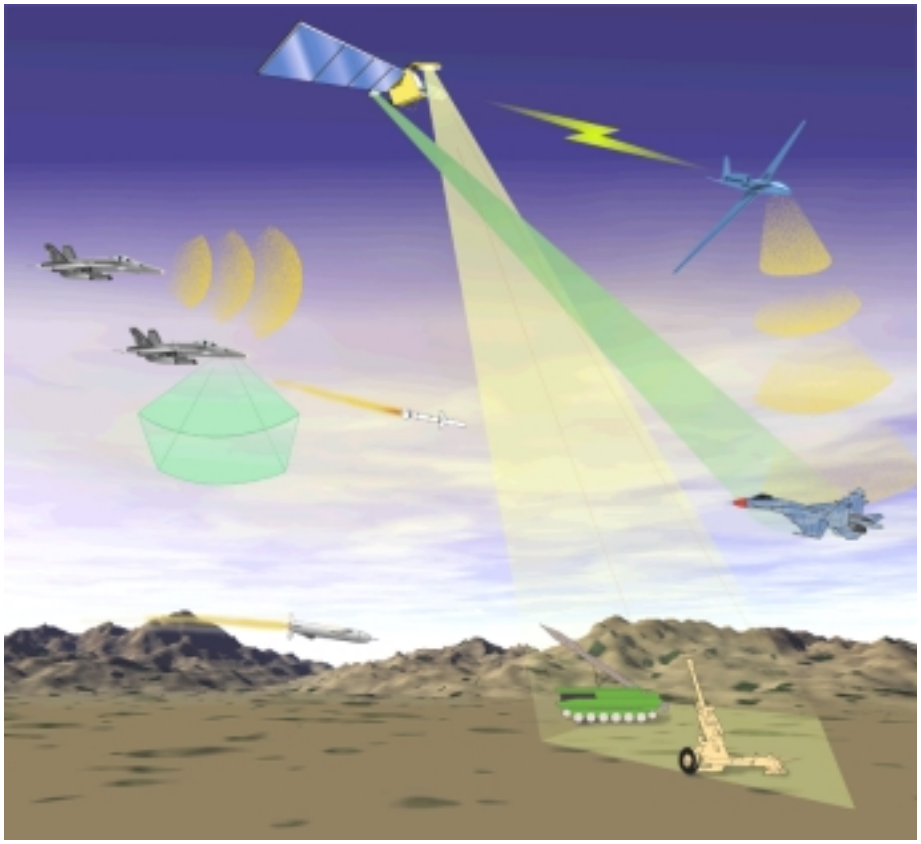
Todd Kastle, AFRL/SNRR, todd.kastle@wpafb.af.mil

Primary End-Users of MEMS CTS Are Military Space Commands and Commercial Avionics Manufacturers

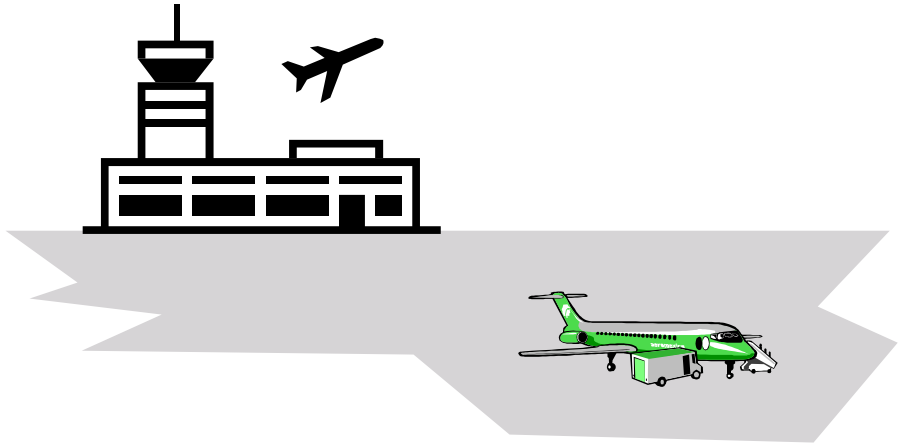
AF DUS&T

Raytheon

Large Space-Based ESAs for Military Missions



Low-Cost ESAs for Commercial Avionics



Todd Kastle, AFRL/SNRR, todd.kastle@wpafb.af.mil

MEMS CTS ESA Offers Benefits that Impact Military and Commercial Products

AF DUS&T

Raytheon

New Military Capabilities

- Helps enable large light weight apertures for SAR/GMTI and AMTI missions
- Facilitates a wide range of options for thinned (lower T/R module count) ESA architectures
- Develops lower cost ESA products for military radar and communication systems in general
- Provides MEMs phase shifters with lower cost, insertion loss and weight
- Develops MEMs switches important to other military applications, e.g., low loss switched filter banks for wideband radar receiver

Commercial Aircraft Radar/Comm

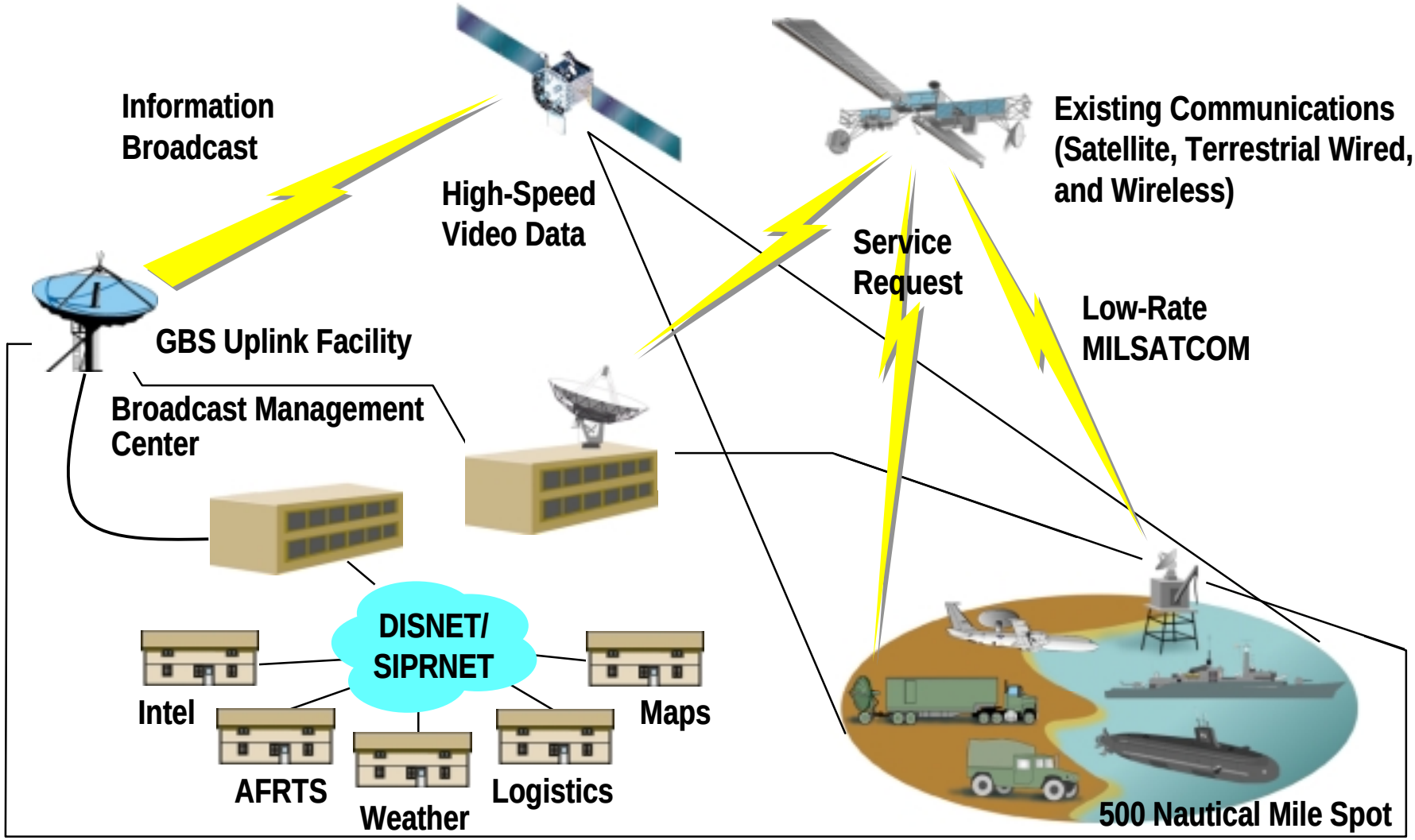
- Reduces ESA cost
- Provides enhanced capabilities for situational awareness and weather radar on commercial aircraft
- Provides product discriminant features
- Delivers significant reductions in life cycle maintenance costs
- Benefits other commercial applications of ESAs:
  - Satellite communications from a car, boat or plane
  - Automotive adaptive cruise control and collision avoidance

Todd Kastle, AFRL/SNRR, todd.kastle@wpafb.af.mil

Military's Global Broadcast Service (GBS) Architecture Exemplifies a SATCOM System

AF DUS&T

Raytheon



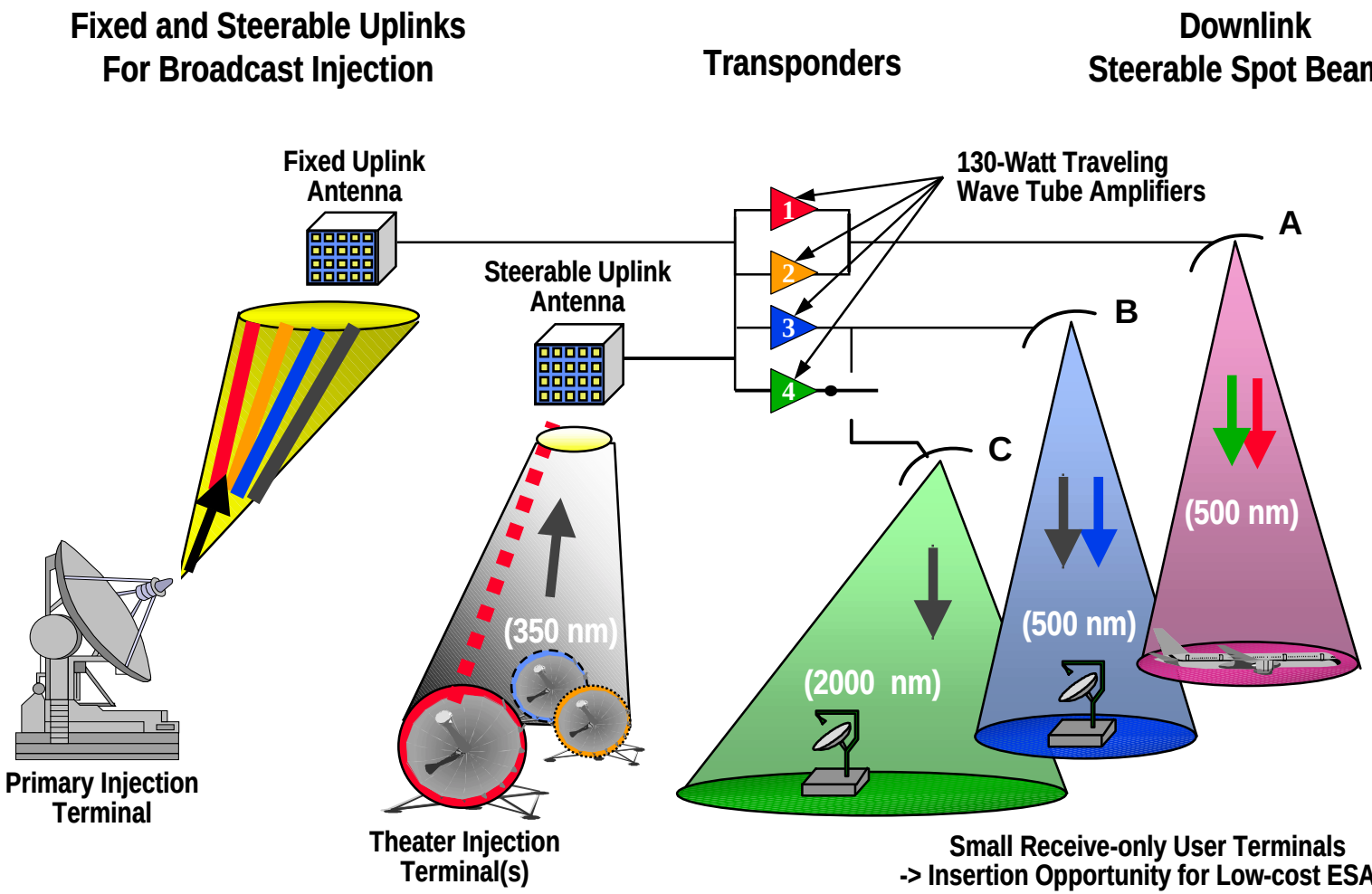
Todd Kastle, AFRL/SNRR, todd.kastle@wpafb.af.mil

Low-cost ESA's Needed for Small Receive-only Antennas in a GBS-type SATCOM System

AF DUS&T

Raytheon

Two 30-GHz uplinks (1 fixed & 1 steerable) with three steerable 20-GHz downlink spots

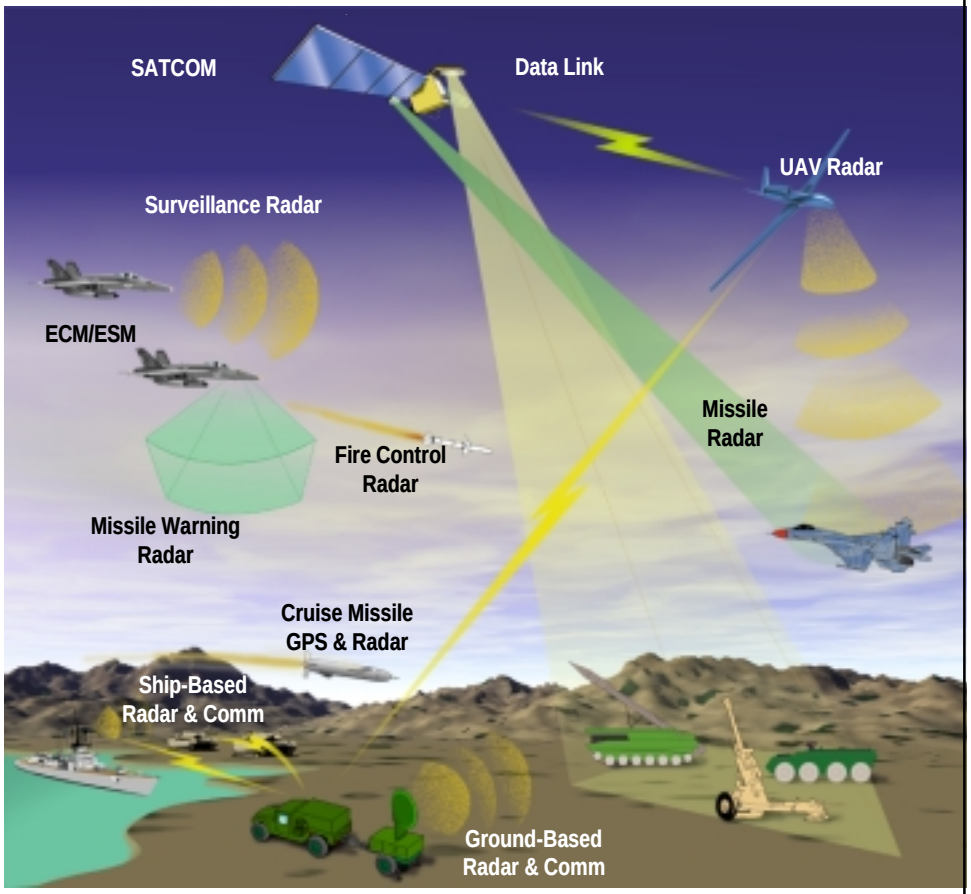


Todd Kastle, AFRL/SNRR, todd.kastle@wpafb.af.mil

Space-Based Sensors Comprise One of Many Opportunities for Insertion of RF MEMs Technologies into Military Systems

AF DUS&T

Raytheon



Features	Benefits
• IC Manufacturing Tools and Processes	• Low Cost
• Small, Light Weight, Low Control Power	• Reduces Prime Power • Reduces Payload Weight
• Low Insertion Loss with High Isolation	• Reduces Prime Power • Reduces Payload Weight
• Wide Bandwidth	• True-Time Delay Devices
• All Solid State Integrated Construction	• Increases Reliability
• Separation of DC Control and RF Circuits	• Eliminates Need for DC Block and Simplifies Circuit
• Integration of Antenna with Antenna Subsystem Possible at Millimeter-wave Bands	• Reduces System Complexity and Integration Costs

Radar/Comm/EW Applications:

- Low-Cost ESA's for Radar/Comm/EW
- Miniature, Wideband Receivers and Transmitters
- Key Components:
  - RF Switches (Series and Shunt)
  - Phase Shifter
  - Tunable Filter Bank
  - Antenna/Feed

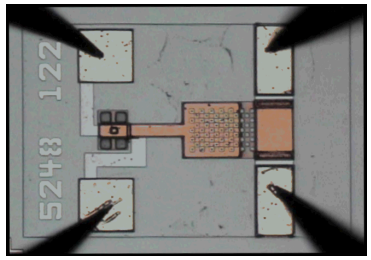
Todd Kastle, AFRL/SNRR, todd.kastle@wpafb.af.mil

RF MEMS Switches Are Fundamental to Device Concepts with Low Cost/Size/Weight/Prime Power Requirements

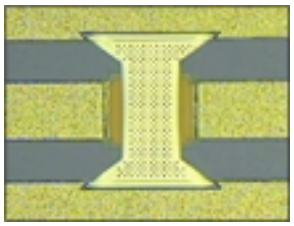
AF DUS&T

Raytheon

HRL
Metal-Metal Contact
Series Switch



Raytheon Texas
Membrane
Shunt Switch



RF MEMS Key Features

- Low cost
- Low insertion loss
- High isolation
- Wide bandwidth
- Small size
- Low weight/power
- Simple circuits

RF MEMS Key Issues

- **Reliability**
- **Packaging**
- RF Power Handling
- Actuation Voltage
- Switching Speed

Communications

- Phase Shifter
- Tunable Filter Bank
- Reconfigurable Antenna
- Integrated Subsystems

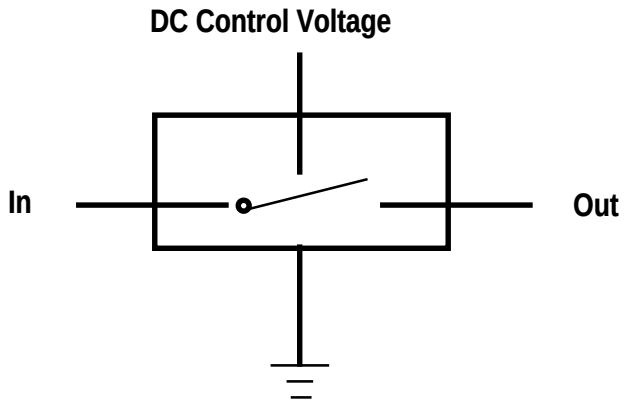
Todd Kastle, AFRL/SNRR, todd.kastle@wpafb.af.mil

RF MEMs Switches Are Much Simpler than PIN Diode Switches

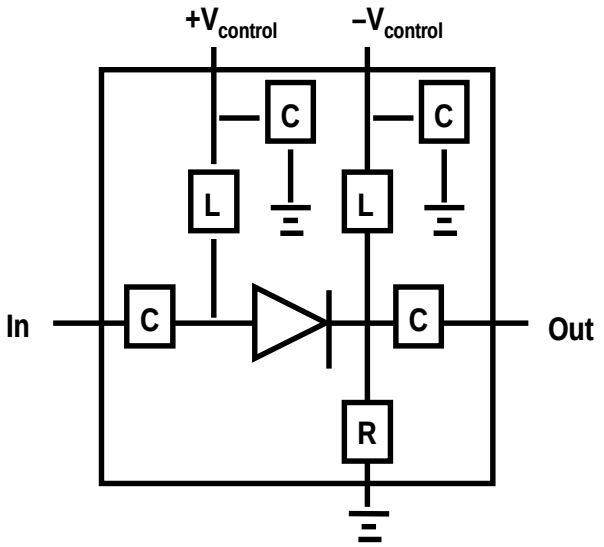
AF DUS&T

Raytheon

Simple RF MEMs Switch Circuit



More Complex PIN Diode Switch Circuit



0.0025 sq inch	Area	0.25 sq inch
One	DC Control Voltages	Two: + and –
< 1 nanowatt	DC Control Power	~300 milliwatts
No	DC Block	Yes

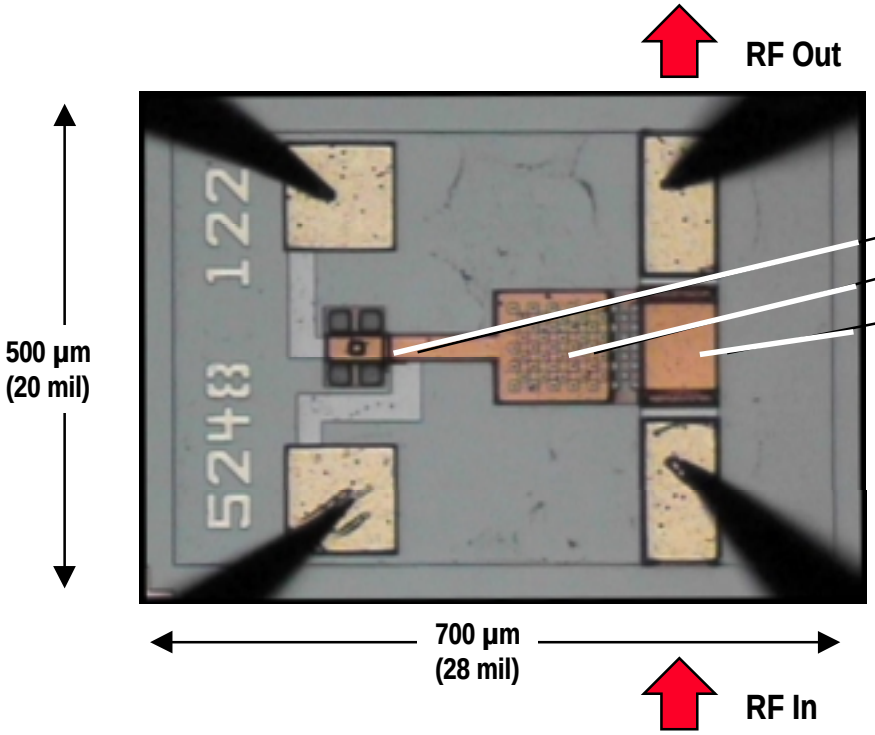
Todd Kastle, AFRL/SNRR, todd.kastle@wpafb.af.mil

HRL RF MEMs Switch is a Metal-Metal Contact Series Switch

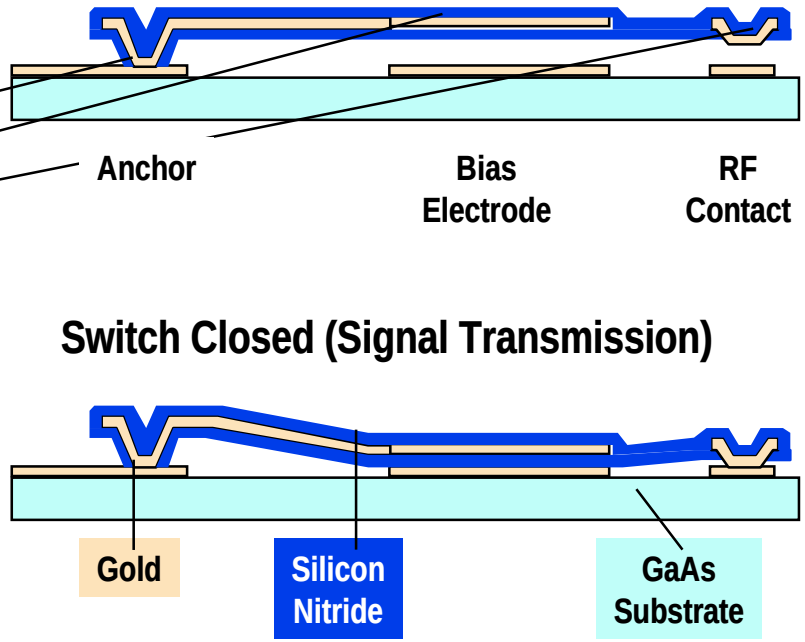
AF DUS&T

Raytheon

Top-View



Side-View



- Electrostatic actuation: 20–40 V
- Switching time: 20–40 µsec
  - Depends on gap and voltage

- Nitride/gold/nitride tri-layer prevents creep
- Fabrication process is compatible with other substrate materials like high resistivity silicon

Todd Kastle, AFRL/SNRR, todd.kastle@wpafb.af.mil

OUTLINE

AF DUS&T

Raytheon

Millimeter Wave Electronically Scanned Array

MEMS Continuous Transverse Stub

MEMS Electronically Scanned Array

Summary

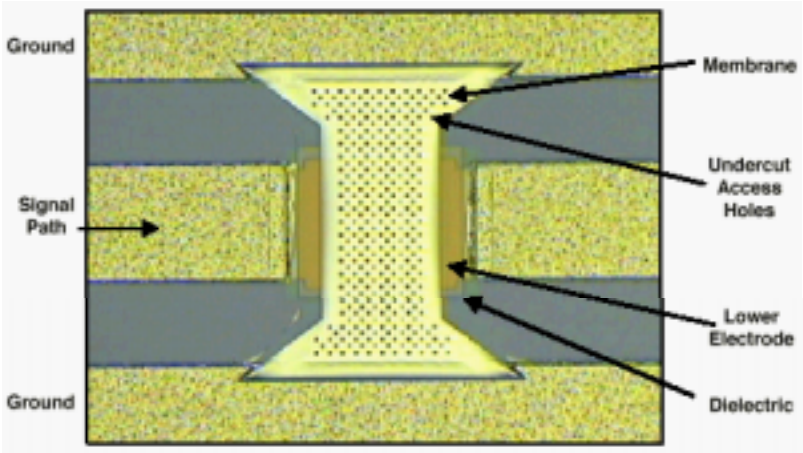
Todd Kastle, AFRL/SNRR, todd.kastle@wpafb.af.mil

Raytheon Texas RF MEMs Switch is a Membrane Shunt Switch

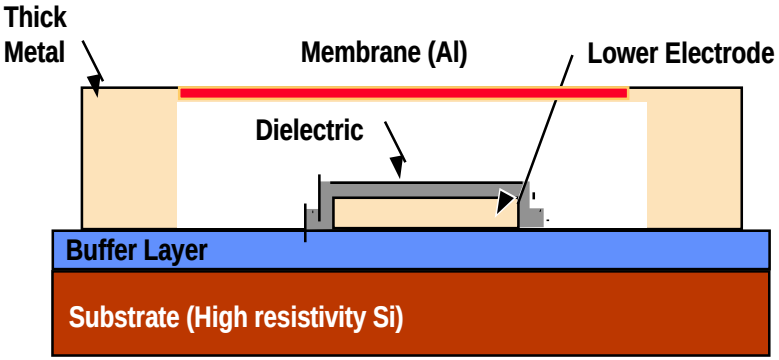
AF DUS&T

Raytheon

Top-View



Side-View



Switch Up (Signal Transmission)

Switch Down (Signal Isolation)

- Electrostatic actuation: 30–50 V
- Switching time: < 2 µsec
  - Depends on gap and voltage

- Fabrication process is compatible with other substrate materials like GaAs.

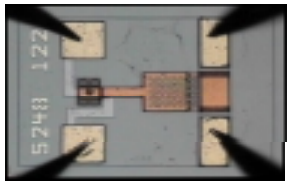
Todd Kastle, AFRL/SNRR, todd.kastle@wpafb.af.mil

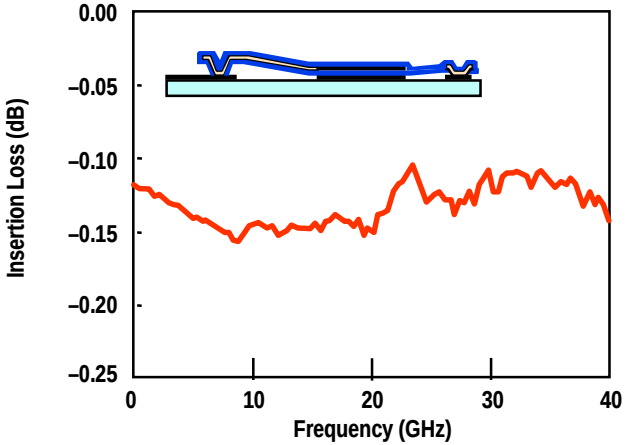
Raytheon and HRL RF MEMs Switches Have Complementary Performance Over Wide Bandwidth

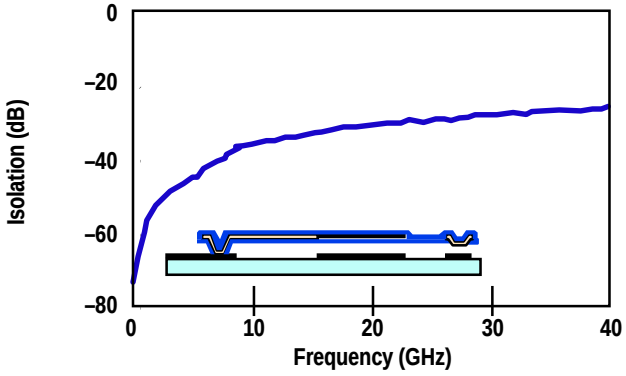
AF DUS&T

Raytheon

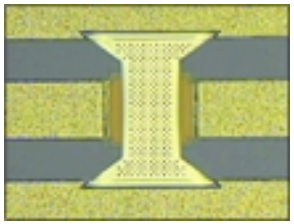
HRL
Metal-Metal
Contact
Series Switch

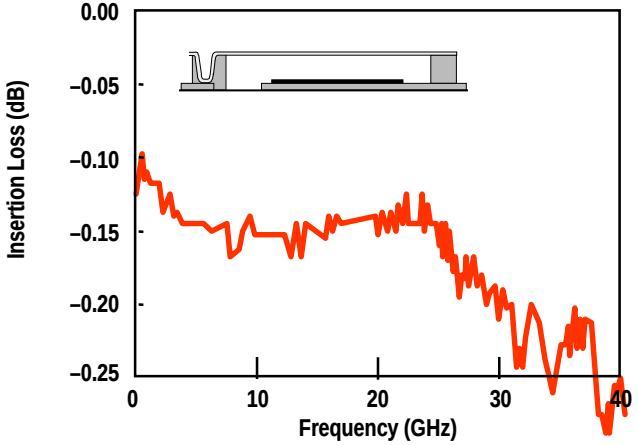


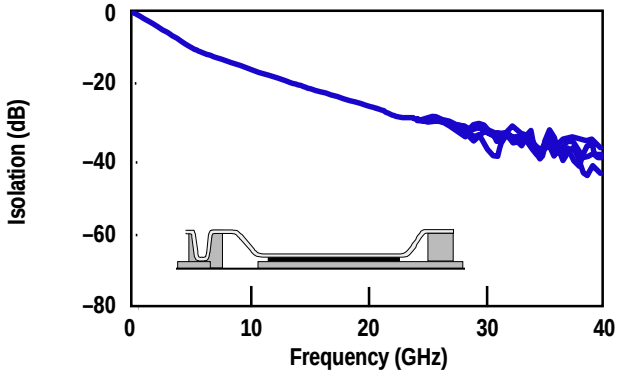




Raytheon
Membrane
Shunt Switch







Todd Kastle, AFRL/SNRR, todd.kastle@wpafb.af.mil

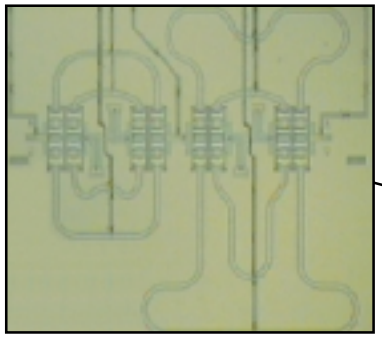
MEMs ESA
4-Bit X-Band Phase Shifter Development

AF DUS&T

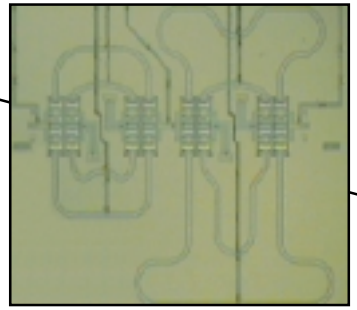
Raytheon

MAFET *DUS&T*

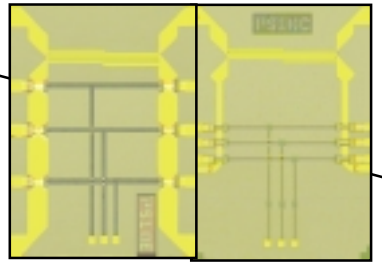
Loss



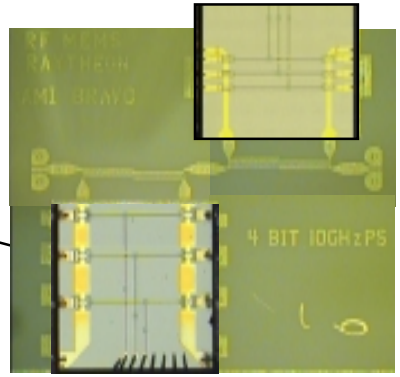
6.8 dB loss
4-bit 2x2 Switch Network
(using SP4Ts)
Coplanar waveguide (120/80µm)
Series Inductive matching
Aluminum/Silicon



4.6 dB loss
4-bit 2x2 Switch Network
(using SP4Ts)
Coplanar waveguide (50/35µm)
Shunt Inductive Matching
Aluminum/Silicon



1.4 dB loss
4-bit 2x2 Network
Microstrip/Reflection Topology
"Hot" MEMS switches
No resonant matching
Gold/Silicon



1.15 dB loss
4-bit 2x2 Network
Alumina Couplers
"Hot" MEMS switches
Reduced parasitics
Gold/Silicon

Iteration

Todd Kastle, AFRL/SNRR, todd.kastle@wpafb.af.mil

RF MEMs Phase Shifters (4-bit) Are Projected to be Low Loss and Low Cost

AF DUS&T

Raytheon

Phase Shifter Type	Control Power	Switching Time	Peak RF Power Handling	One-way RF Loss	Weight/ Volume	Cost
• MEMs						
– Single pole single-throw						
• Metal-metal *series*	*<0.01 mW*	*<10 µsec*	*<10 W*	*0.6–0.8 dB*	*Low*	*<$1**
• Membrane *shunt*	*<0.01 mW*	*<10 µsec*	*<10 W*	*0.6–0.8 dB*	*Low*	*<$1**
– Single pole multi-throw	*<0.01 mW*	*<10 µsec*	*<10 W*	*0.5–0.7 dB*	*Low*	*<$1**
• Ferrite (analog)	400 mW	10 µsec	100 W	1 dB	High	$75
• GaAs						
– PIN diode	80 mW	10 nsec	10–100 W	3–4 dB	Low	$20
– FET	10–20 mW	<1 nsec	1 W	5 dB	Low	$20

*** Projected cost for MEMs phase shifters in production.**

Todd Kastle, AFRL/SNRR, todd.kastle@wpafb.af.mil

OUTLINE

AF DUS&T

Raytheon

Millimeter Wave Electronically Scanned Array

MEMS Continuous Transverse Stub

MEMS Electronically Scanned Array

Summary

Todd Kastle, AFRL/SNRR, todd.kastle@wpafb.af.mil

Summary

AF DUS&T

Raytheon

The Air Force and Raytheon are developing low cost MEMS Phase shifters to be combined with CTS and other types of low cost apertures to drive the cost of Radar and Communication systems down!

Todd Kastle, AFRL/SNRR, todd.kastle@wpafb.af.mil

Points of Contact

AF DUS&T

Raytheon

Air Force Research Laboratory

Todd Kastle (937) 255-6427 ext. 4328

Raytheon

William Milroy (310) 334-8761 (CTS Inventor)

Ralston Robertson Ph.D. (310) 334-1872 (W-Band)

Brian Pierce Ph.D. (310) 334-8299 (metal to metal MEMs)

Carroll Caddel (972) 575-6922 (membrane shunt MEMs)